Insurance Institute for Business & Home Safety

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Wind Flow Validation Summary

IBHS Research Center Validation of Wind Capabilities

The Insurance Institute for Business & Home Safety (IBHS) Research Center full-scale test facility provides opportunities to simulate natural wind conditions in a controlled atmosphere.

Objective

A core element of the scientific commissioning of the Insurance Institute for Business & Home Safety (IBHS) Research Center full-scale test facility is the development and validation of wind flow simulation capabilities. IBHS research engineers performed a series of tests to validate wind capabilities of the facility including: uniform flow tests; turbulent shear flow tests; and tests during which specific time histories obtained from real world extra-tropical winds, thunderstorms and hurricanes are reproduced. This document summarizes results of the flow commissioning efforts. In addition, detailed information about the size and construction of this world-class, unique facility can be obtained on the IBHS website at www.disastersafety.org.

The overarching goal has been to ensure that laboratory-simulated flow conditions accurately replicate both: 1) a variety of scientifically accepted standard flow conditions, and 2) time histories of specific real-world wind events, including thunderstorm winds, extra-tropical winds and hurricane winds. In addition, IBHS researchers have been seeking to learn enough about interactions between the various systems to allow rapid development of control functions necessary to simulate a specific event or flow condition.

Technical Approach

The development of flow simulations in the new IBHS Research Center have been carried out following a systematic step-by-step process, with additional complexities in the control system and algorithms introduced into each series of tests.

The initial series of tests were designed to generate uniform flow across the fan's 15-cell array. The array contains 105 nearly 6 ft. diameter fans; the fans are set in five columns; each column contains three vertically placed cells; each cell contains either six or nine individual fans. In these initial tests, directional vanes were held in a steady-state neutral position, aligned with the mean flow direction through the test chamber. These tests provided a measure of flow uniformity across the jet, as well as measurements of minimum turbulence levels associated with constant steady wind flows. Next, directional vanes were maintained in the same steady-state position, while fan speeds were varied to replicate real, full-scale wind speed time histories of the variations observed in thunderstorm and hurricane events. In these tests, wind speeds were the same in all cells.

Once the control of fan speed variations were evaluated, the variation in mean wind speed with height for open terrain (ASCE 7-10 exposure C) and suburban terrain (ASCE 7-10 exposure B) was introduced by varying wind speeds in different rows of cells. Initial tests were conducted with fans in each cell operating at a constant speed. Then, the variation in mean speed with height was superimposed on the along-wind speed variations to create a first-stage turbulent boundary layer flow. Once shear flow with varying along-wind gusts was successfully produced, directional vanes were activated and relationships between control algorithms for the vanes, derived from directional variations in winds measured at an anemometer location and the along-wind variations created by changing fan speeds were developed. Resulting wind speed and wind direction measurements obtained were compared with target winds, and algorithms were modified until target flow conditions were reproduced. Finally, lateral and vertical variations in wind speeds produced in each cell and lateral variations in the vane direction control algorithms to simulate vertical and lateral coherence in real-wind events were introduced, where the correlation of wind speed fluctuations decreases as frequency increases and lateral or vertical separation increases.

The tests were repeated with tapered spires installed in the straight portion of the inlet contraction just before wind enters the test chamber. These tapered spires helped to smooth variation in mean wind speed with height, and introduced small-scale turbulence (fluctuations in wind speed) that helped improve simulation of gust characteristics of natural winds. Figure 1 depicts the tapered spires installed in the lower and middle cells. To collect the desired data, eight R.M. Young wind monitor anemometers, two modified Gill UVW anemometers, and two Cobra probes were placed along a horizontal gantry apparatus. The gantry is shown in Figure 1 and examples of each piece of equipment are shown in Figure 2. An additional R.M. Young wind monitor anemometer, located at the middle cell of the middle column in the fan array and fixed at a position of 4.9 m (16 ft) above ground level, was used as a reference throughout each test series as the gantry was moved. Additional details on the data acquisition system are available in the proceedings of the 13th International Conference on Wind Engineering (ICWE).

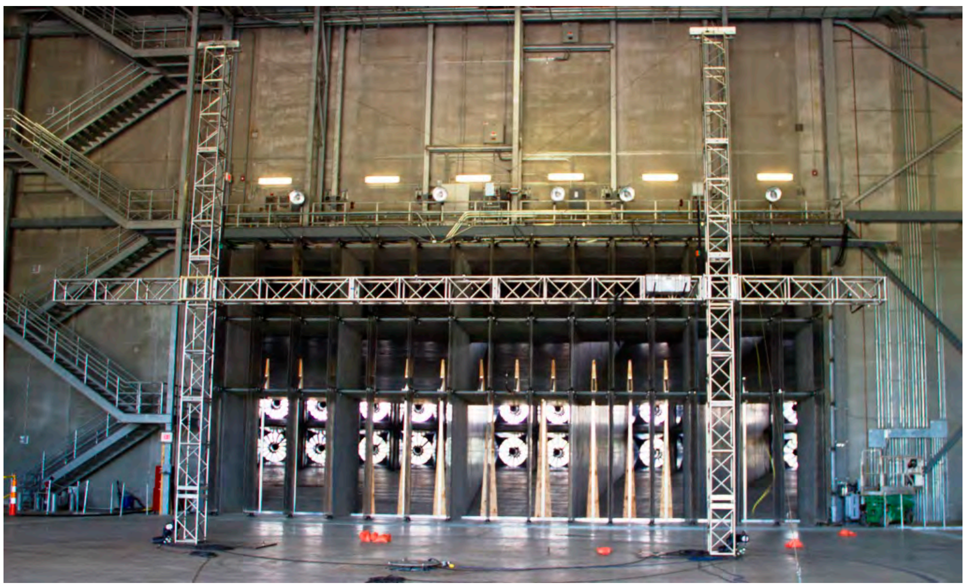

Figure 1: The horizontal gantry located near the front of the 55-foot turntable in the test chamber.

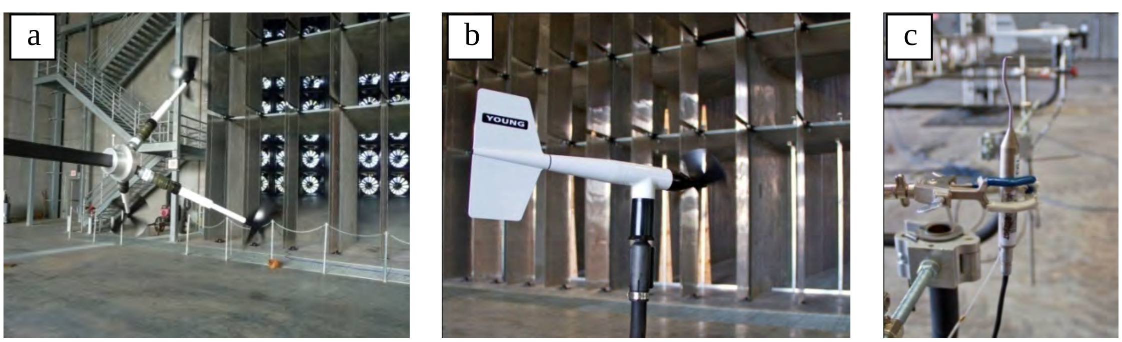

Figure 2: Flow measurement sensors: a) modified Gill UVW anemometer; b) R.M. Young wind monitor anemometer; and, c) Cobra probe on horizontal gantry.

Observations and Data Analysis

Uniform Smooth Flow

Uniform smooth flow is characterized by minimal or no change in wind speed across the entire cross-section of the air jet. Consequently, there is no vertical or lateral variation in wind speed. Furthermore, the fans are run at a constant speed, so there is little or no variation in wind speed with time. This flow condition provides a great deal of insight into the fundamental quality of flow produced in the facility. The goal is to achieve a flow with small variations in mean or average wind speed across the jet and small fluctuations in speed as defined by a low turbulence intensity. The turbulence intensity is defined as the standard deviation of wind speed and its mean value divided by mean wind speed. These tests, conducted at approximately 10 percent, 30 percent, and 50 percent of maximum fan speeds, were designed to quantify the level of uniformity and demonstrate that there were no large differences in flow across the fan array.

Minor adjustments were made to the fan operating speeds to ensure uniform flow was achieved at different vertical positions. Because of the larger contraction ratio for the upper rows of cells, as opposed to the bottom row of cells, the lower cell fans had to be operated at a higher percentage of maximum fan speed to achieve uniform flow. Data were collected at eight height levels for anemometers positioned along the gantry. Table 1 summarizes results of these uniform flow tests for one set of fan speeds, which are graphically displayed in Figure 3 (on page 5). Variation in mean wind speed of less than +/- 5 percent across the core testing area and less than +/- 6 percent across the entire jet is quite good for a facility of this size, and comparable to uniformity achieved in other large wind tunnels used for building aerodynamic studies. The average turbulence intensity of 2 percent to 3 percent and the maximum value of 3.7 percent in the core area is quite good, as it allows a low turbulence base upon which to add active and passive controls for achieving target turbulence intensities for natural winds that normally exceed 15 percent to 18 percent.

Table 1: Uniform wind flow created within the test chamber

	Wind Speed Profile		Turbulence Intensity Profile	
	Mean wind speed	Variation	Average TI	Range
Entire flow field: 65ft w ×30ft h	53 mph	5.8%	2.6%	0.9% to 14.7%
Core testing area: 55ft w ×25ft h	54 mph	4.9%	2.0%	0.9% to 3.7 %

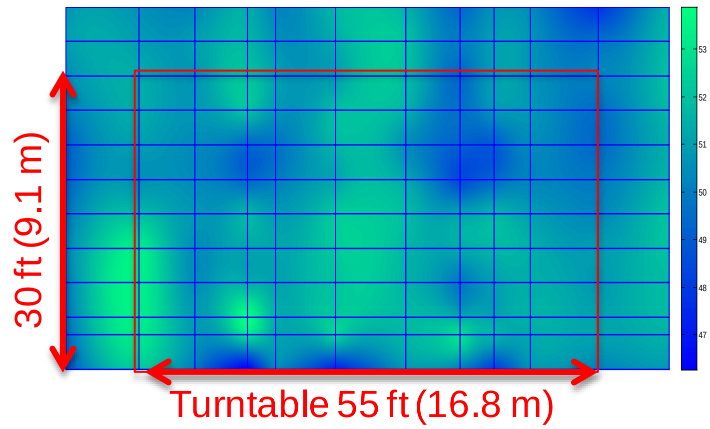

Figure 3: Uniform wind flow in the test chamber; changes in color show slight variations in mean wind speed.

Replicating full-scale wind speed time histories

Tests were designed to replicate real-world, full-scale wind collected from the Texas Tech University (TTU) site to assist with the pressure validation research project. The Wind Engineering Field Research Laboratory (WERFL) at TTU includes a flat roof full-scale test building, currently instrumented with 204 pressure taps, which has been used to collect wind-induced pressure data in a natural, open exposure environment in Lubbock, Texas, since 1989. Data from the WERFL building have been used in the validation of numerous wind tunnel tests and computational fluid dynamic analyses over the past two decades, and information about the WERFL site is readily available in wind engineering literature.

These tests not only considered reproducing full-scale wind speed time histories, but also required creating a wind direction time history by controlling wind vanes. Height-adjusted, full-scale wind records were filtered using a 7-second moving average. However, in this case, records were down sampled to 2 Hz to be compatible with the command speed for both the fan speed and rotation angle position PLC logic controllers. Figure 7 (on page 7) shows a 100-second segment of wind speeds measured at TTU and the resulting 2-Hz target wind speed record used as input to control the fans. Figure 8 (on page 8) shows the corresponding 100-second segment of wind direction measured at TTU, along with the resulting 2-Hz target wind direction record used as input to control the vanes. Figures 9 (on page 9) and 10 (on page 10) show wind speed measurements made at the leading edge of the turntable that correspond to this same record. It should be noted that IBHS measurements were made using the tapered spires discussed in the preceding section. These spires were included primarily to add high-frequency, small scale turbulence that was missing because the fans produced too smooth a flow (i.e., too little high-frequency turbulence). Spire use provided both a smoother variation in mean wind speed with height, and introduction of additional high-frequency turbulence in the simulated flow. The combination of influence of the spires and relatively rapid changes in wind speed in the TTU record relative to fan ramp speed produced a somewhat poorer replication of the TTU input time history than might be expected based on comparisons shown in Figures 4 (on page 4) and 5. However, it should be noted that the time scale has been expanded so that the Figures show an expanded view of a 100-second segment of the record, instead of the 900-segment and 1800-second segments of Figures 4 and 5.

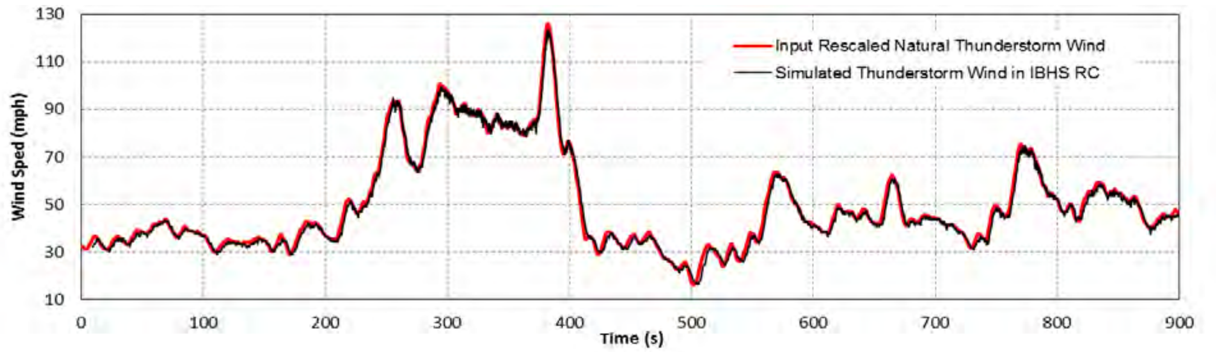

Figure 4: Comparison of simulated winds and input rescaled natural thunderstorm winds.

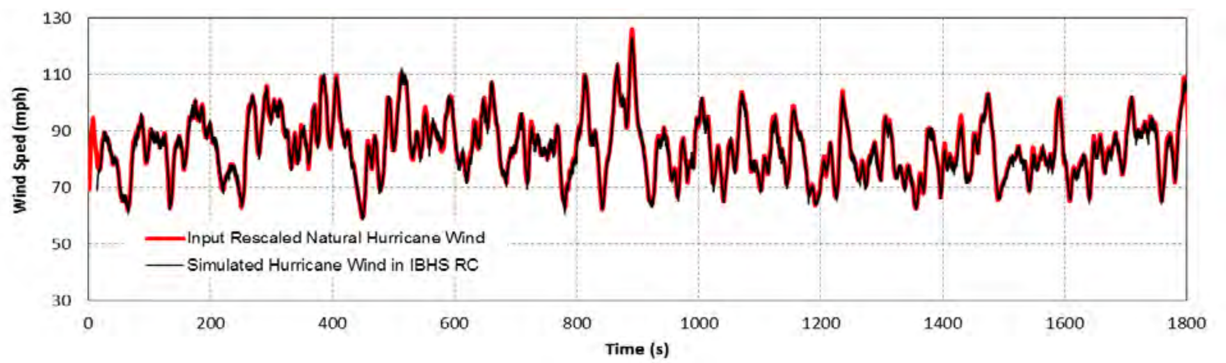

Figure 5: Comparison of simulated winds and input rescaled natural hurricane winds.

Open and suburban terrain profiles

Tests also were designed to replicate mean wind profiles for open terrain (ASCE 7-10 exposure C) and suburban terrain (ASCE 7-10 exposure B). Unlike uniform flow, these profiles do account for variation in mean wind speed with height due to frictional effects of vegetation, trees and buildings on the earth's surface. Fan speeds for each row were altered until desired results were achieved. After establishing the gross mean velocity profile by varying wind speed in the cells, the mean velocity profile was further smoothed through addition of tapered spires in the bottom and middle cells. The typical open country mean wind profile was created in the full-scale facility, as shown on the right-hand side of Figure 6 (on page 7), where the solid blue line represents the target profile and blue squares represent data collected in the test facility. Large-scale turbulence was introduced by inputting fan speed variations similar to those used to create wind time histories shown in Figure 4 and 5, and by changing wind direction through activation of wind vanes. Using actual data on large-scale fluctuations in along-wind speed and variations in wind direction together with turbulence from the spires provided reasonable simulations of corresponding large-scale longitudinal and lateral wind turbulence, as shown on the left-hand side of Figure 6. A similar procedure was used to achieve the suburban terrain profile.

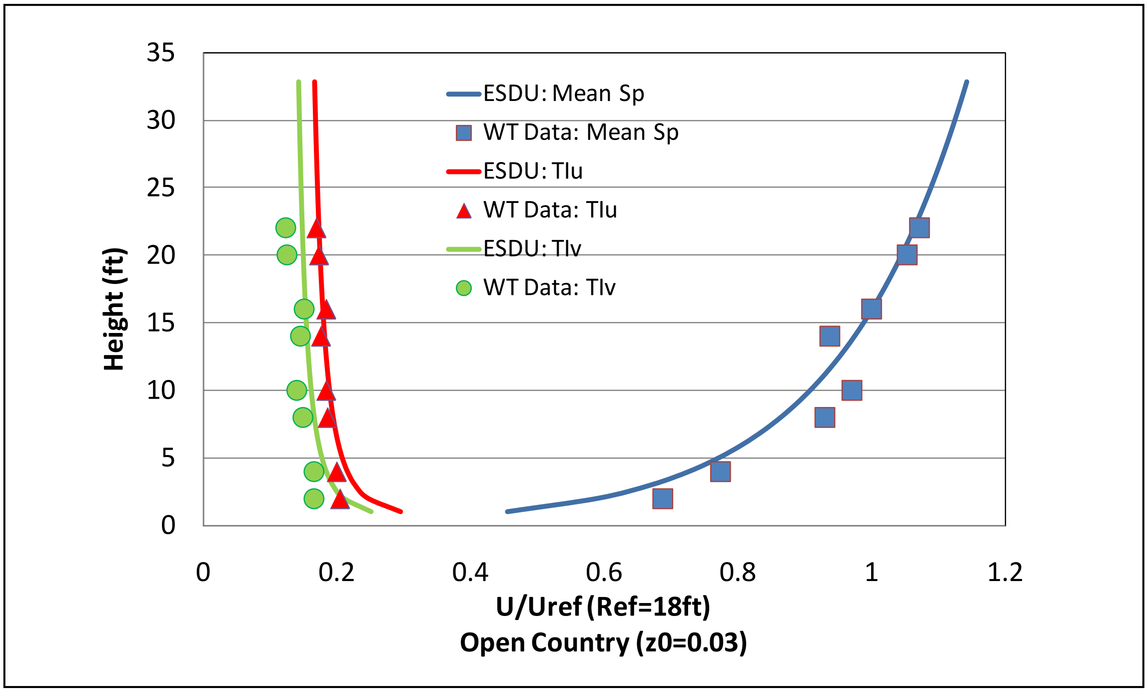

Figure 6: Mean wind speed profile and turbulence intensities for open country.

Replicating full-scale wind speed time histories for pressure testing validation

Finally, tests were designed to replicate real-world, full-scale wind collected from the TTU site to assist with the pressure validation research project. The simulation in these tests not only considered reproducing full-scale wind speed time histories, but also required creating a wind direction time history by controlling wind vanes. Height-adjusted, full-scale wind records were filtered using a 7-second moving average. However, in this case, records were down sampled to 2 Hz to be compatible with the command speed for both the fan speed and rotation angle position PLC logic controllers. Figure 7 shows a 100-second segment of wind speeds measured at TTU and the resulting 2-Hz target wind speed record used as input to control the fans. Figure 8 shows the corresponding 100-second segment of wind direction measured at TTU, along with the resulting 2-Hz target wind direction record used as input to control the vanes. Figures 9 and 10 show wind speed measurements made at the leading edge of the turntable that correspond to this same record. It should be noted that IBHS measurements were made using tapered spires discussed in the preceding section. These spires provided both a smoother variation in mean wind speed with height, and the introduction of additional high-frequency turbulence in the simulated flow. The combined influence of the spires and rapid changes in wind speed in the TTU record relative to the ramp speed of the fans produced a somewhat poorer replication of the TTU input time history than might be expected based on the comparisons shown in Figures 4 and 5. Note that the time scale has been expanded so that the Figures 7 through 10 show an expanded view of a 100-second segment of the record.

All TTU measurements, as well as IBHS facility measurements shown in Figures 7 through 10 were recorded using R.M. Young anemometers that basically filter out high-frequency or small scale content of the flow. Consequently, the unfiltered full-scale wind record is not available. Figure 11 (on page 11) shows wind speeds measured in the IBHS facility, for the same simulated segment of the TTU wind speed record, using a Cobra probe. Figure 12 (on page 12) shows wind directions measured in the IBHS facility, for the same simulated segment of the TTU wind direction record, using a Cobra probe. The Cobra probe is able to measure higher frequency fluctuations in flow and provides a more complete description of the flow that is actually being produced. Tapered spires were included primarily to add high-frequency small scale turbulence that was missing, because the fans produced too smooth a flow (i.e., too little high-frequency turbulence). A preliminary comparison of pressure results suggested that additional high-frequency turbulence was needed, and subsequent test results with the spires in place provided the best match between pressures measured in the IBHS facility and those measured in the field, as well as in boundary layer wind tunnel model studies of the TTU Wind Engineering Field Research Laboratory (WERFL) building.

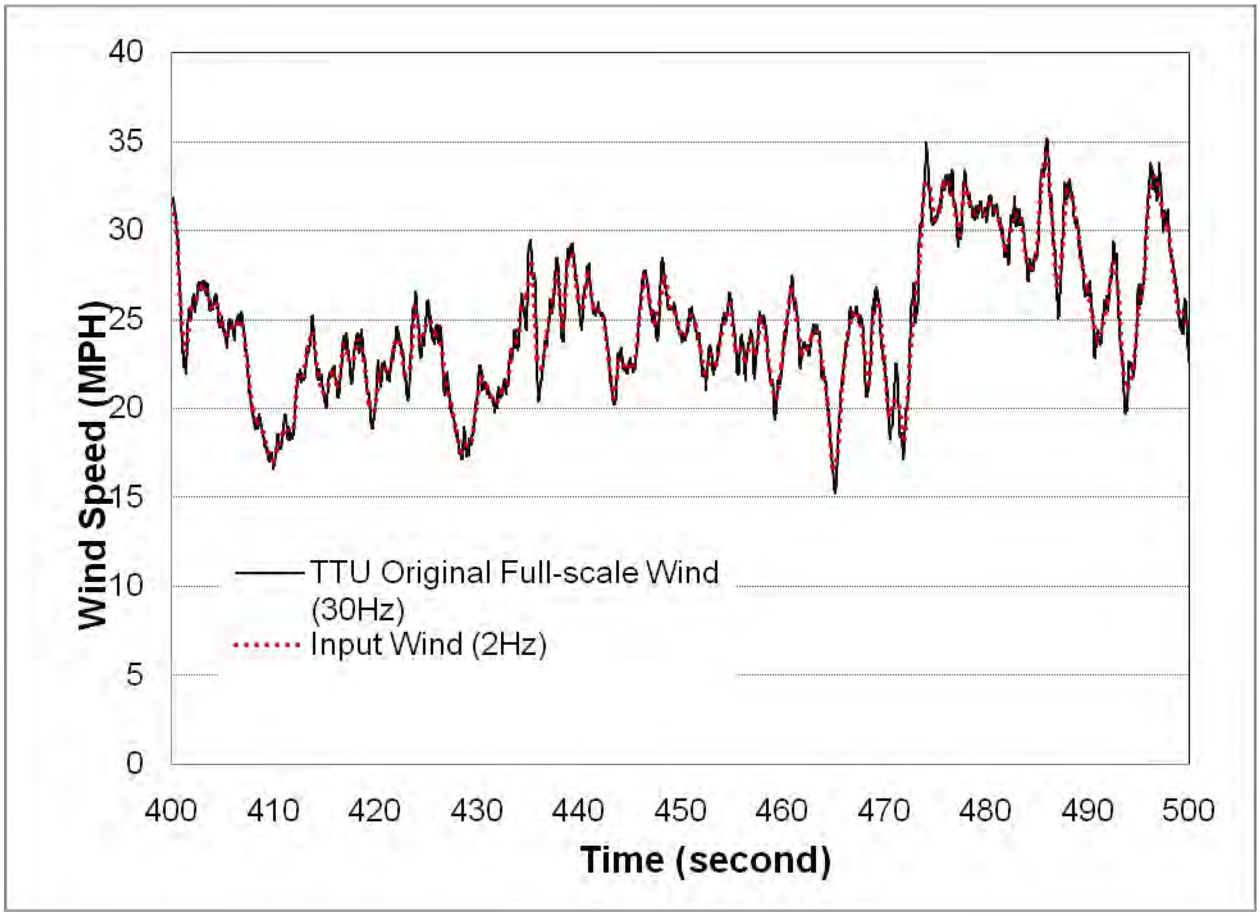

Figure 7: Comparison of TTU field measurements of wind speeds with the target 2-Hz record used as input control for fan speeds.

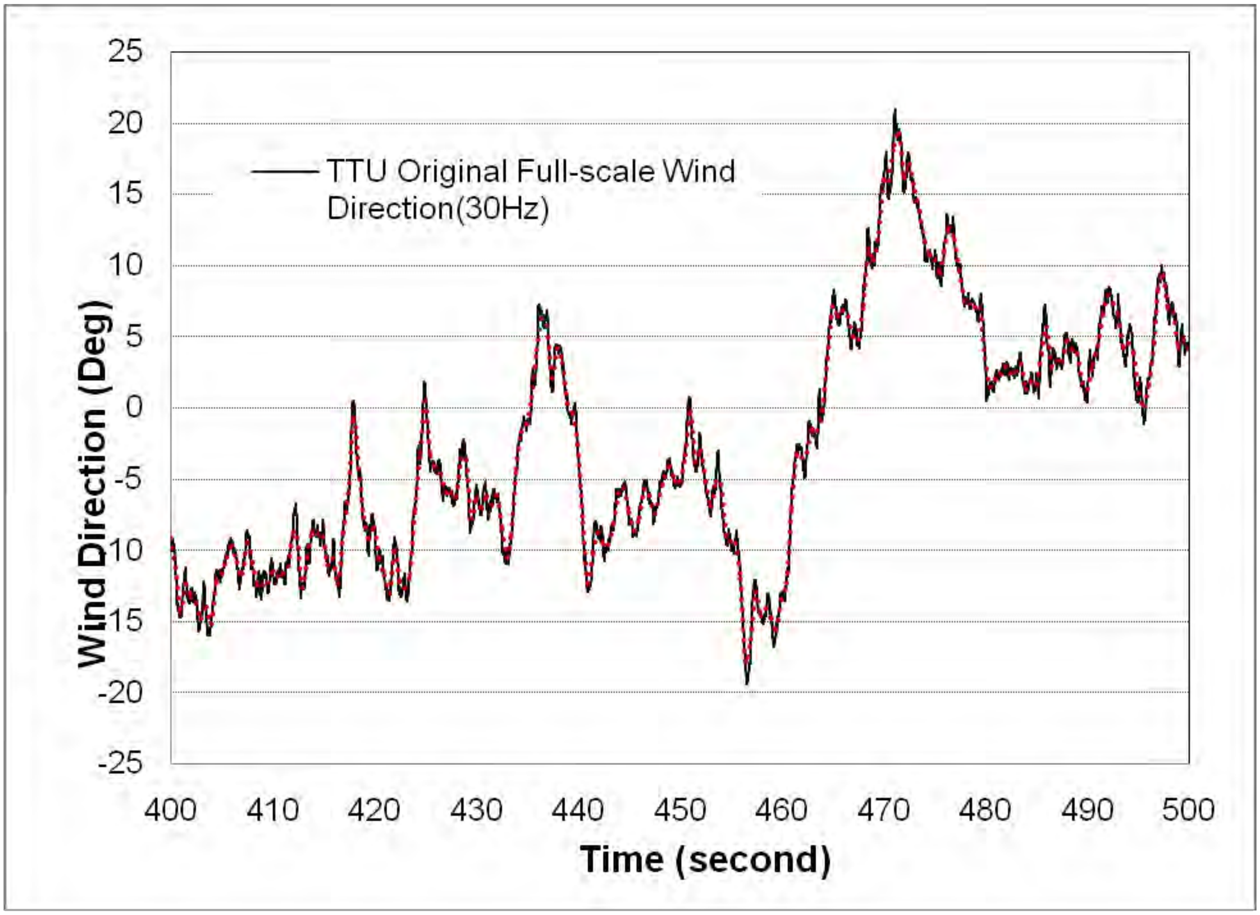

Figure 8: Comparison of TTU field measurements of wind direction with the target 2-Hz record used as input control for vane action.

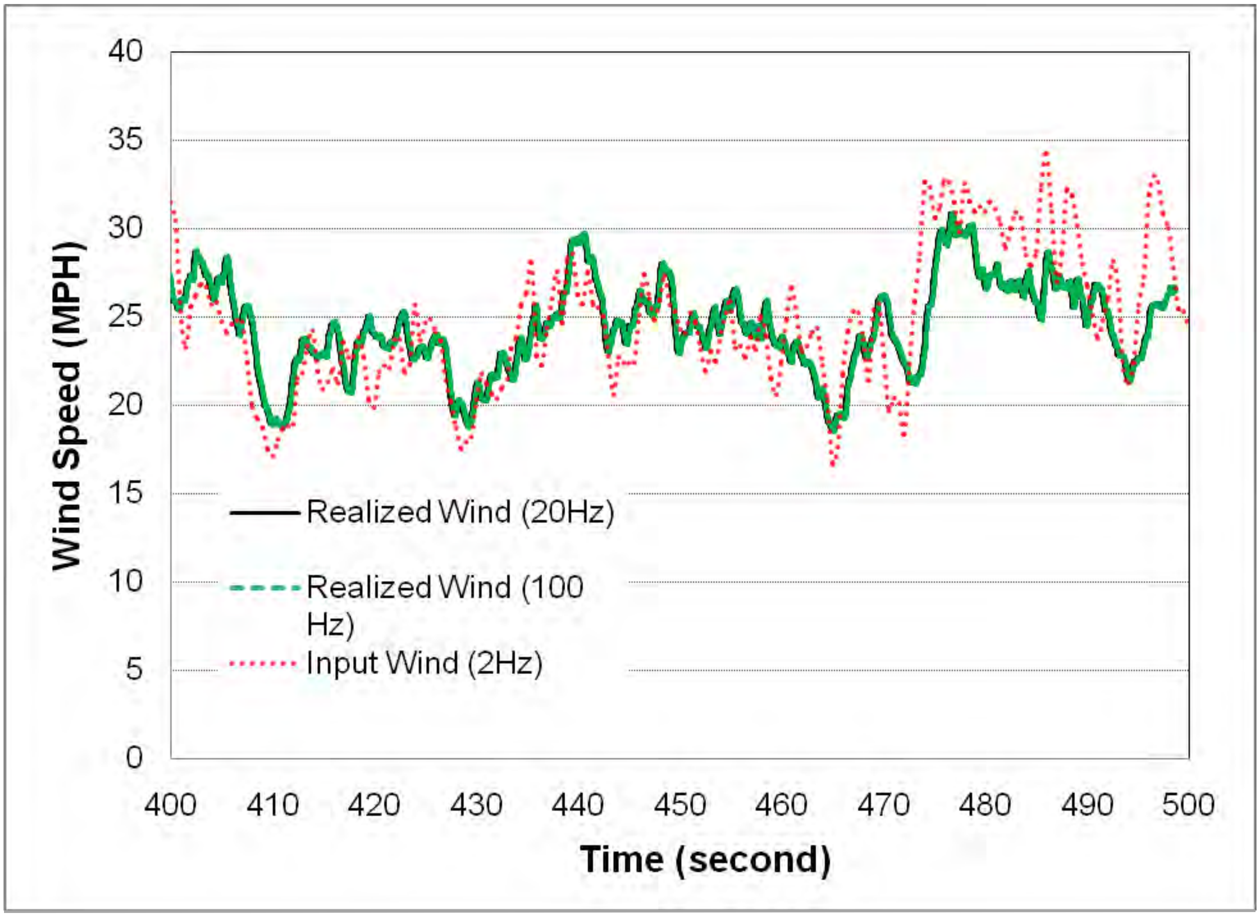

Figure 9: Comparison of input wind speed time history shown in Figure 7 with wind speed time history measured in the IBHS test facility for the corresponding TTU record segment.

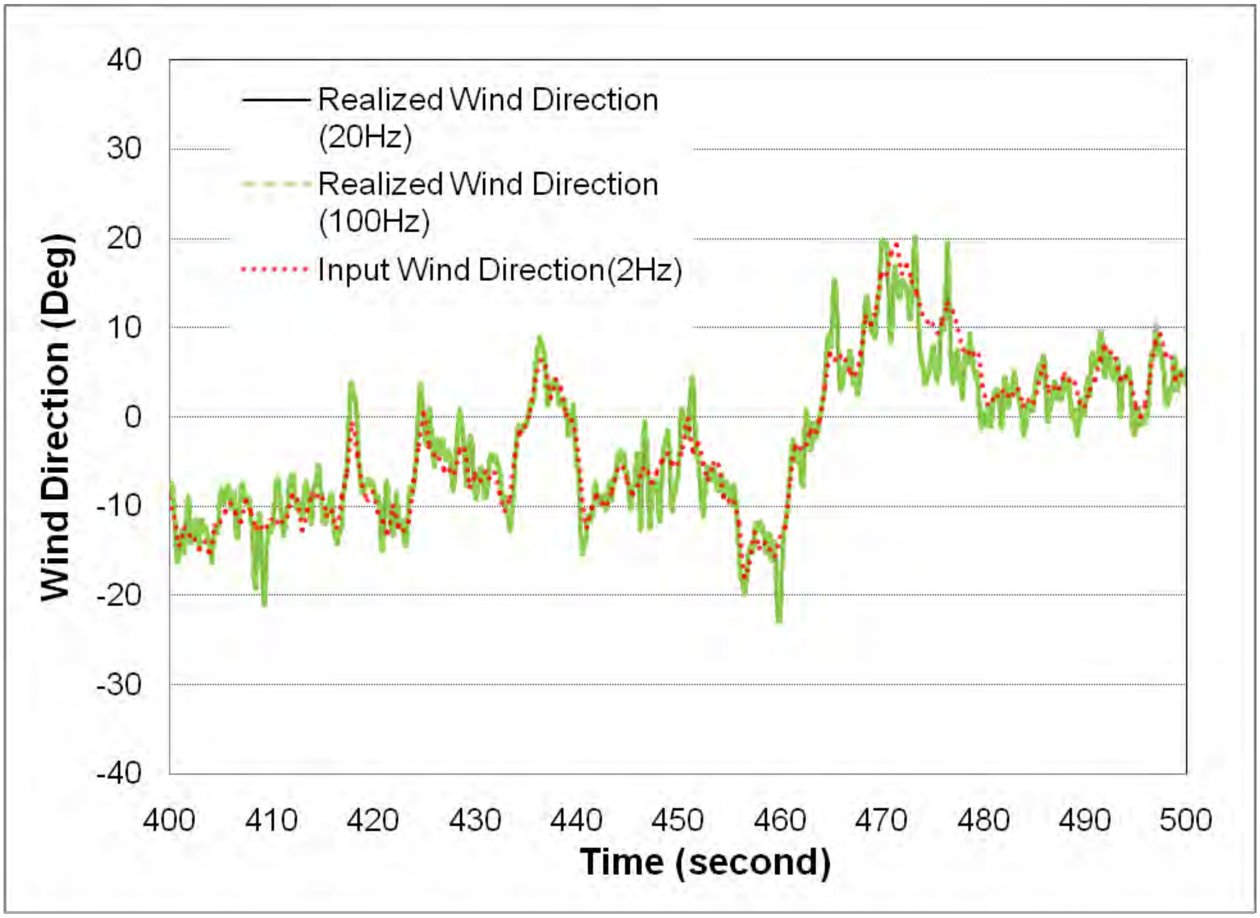

Figure 10: Comparison of input wind direction time history shown in Figure 8 with wind direction time history measured in the IBHS test facility for the corresponding TTU record segment.

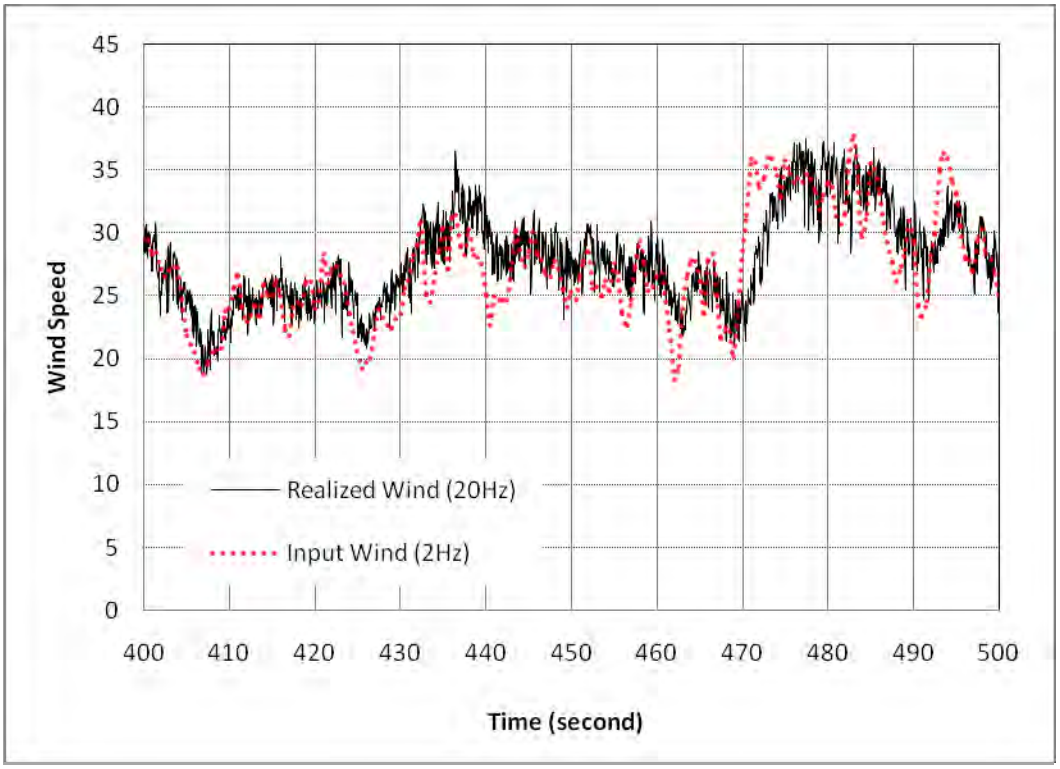

Figure 11: Comparison of input wind speed time history shown in Figure 7 with wind speed time history measured in the IBHS test facility using the Cobra Probe for the corresponding TTU record segment.

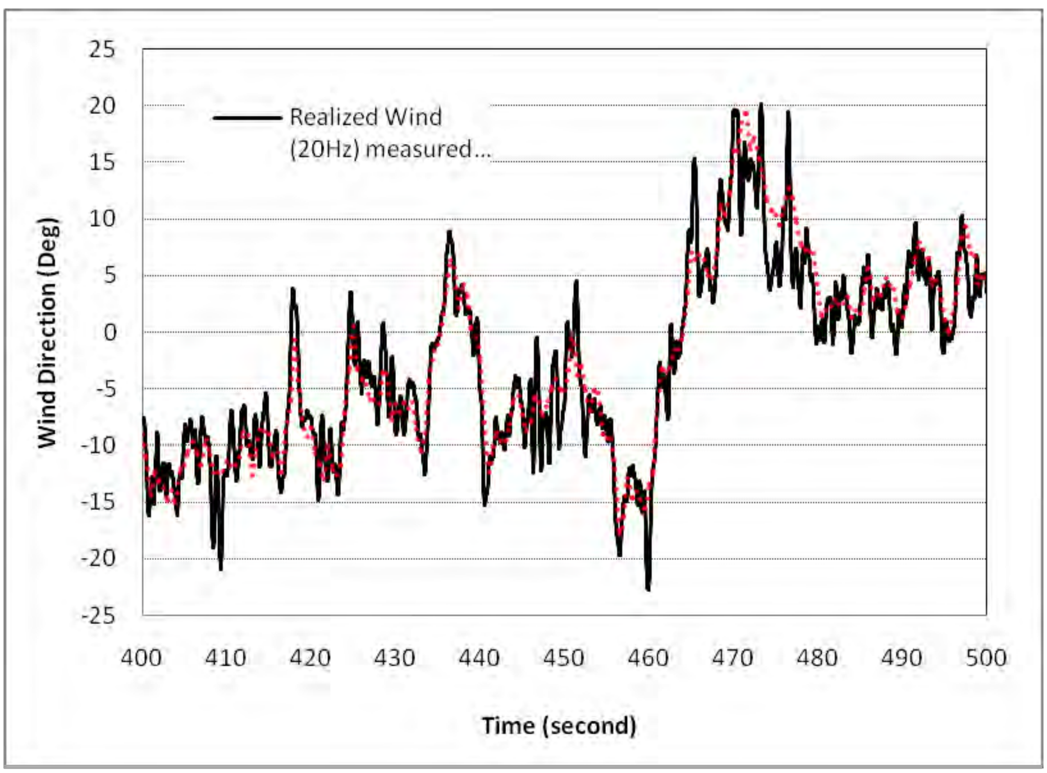

Figure 12: Comparison of input wind direction time history shown in Figure 8 with wind speed time history measured in the IBHS test facility using the Cobra Probe for the corresponding TTU record segment.

Conclusions

Development and validation of flow simulation capabilities for the IBHS Research Center full-scale test facility conducted as part of scientific commissioning of the facility resulted in the following conclusions:

- Uniform wind flow can be effectively achieved in the full-scale test facility.
- By adjusting and controlling fan speed and installing tapered spires, it is possible to simulate target mean velocity profiles and match turbulence characteristics of a target natural wind flow regime in the full-scale test facility.
- Tests conducted as part of this study have displayed and verified the capacity of the full-scale test facility to effectively reproduce large-scale (low frequency) wind gusts and repeatedly produce dominant flow features associated with a specific event.
- Additional tests have displayed and verified the capacity of the full-scale test facility, with newly installed wind spires, to effectively reproduce wind gusts over a wide range of frequencies. Consequently, it is possible to use active control and passive devices to create both dominant flow features and provide needed smaller-scale wind gusts. The IBHS test facility provides a unique test bed where it is possible to develop a greater and more in-depth understanding of the relative importance of various characteristics of natural winds by adjusting or turning on or off low-frequency or high-frequency gusts structures.
- These results confirm the IBHS Research Center's full-scale test facility capability for simulating a wide range of natural winds, where a variety of specialty cases and for parametric studies are present and where various flow characteristics are modified.